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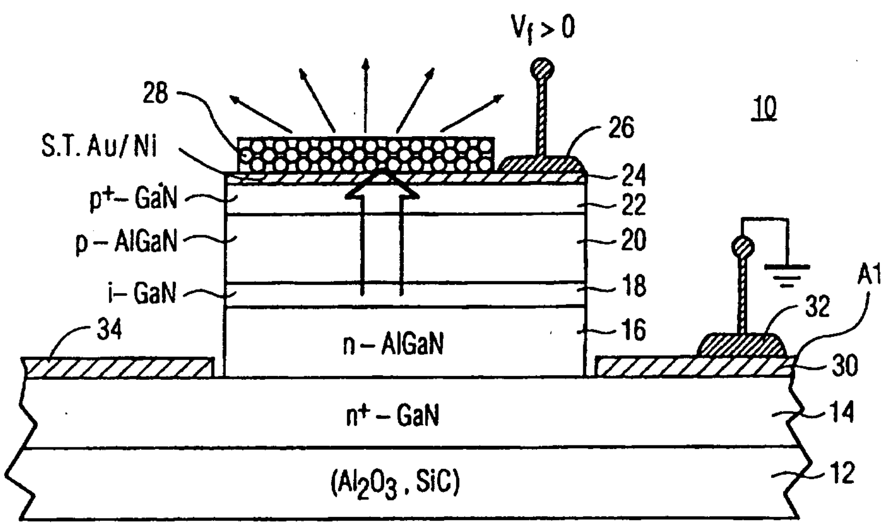


(57) Abstract

Light emitting displays and lamps are produced by photo pumping UV excitable phosphors with UV emitting GaN-based light emitting diodes (LEDs). Resonant cavities are incorporated into the LED structures to both narrow and heighten the emission spectrum. Color displays are produced from arrays of individual LED-phosphor combinations of different colors. Such LED pumped phosphor devices do not require a vacuum environment and operate at much lower voltages than the electron beam pumped phosphor screens of cathode ray tubes (CRTs).

VISIBLE LIGHT EMITTING DEVICES INCLUDING UV-LIGHT EMITTING DIODE AND UV-EXCITABLE, VISIBLE LIGHT EMITTING PHOSPHOR, AND METHOD OF PRODUCING SUCH DEVICES

BACKGROUND OF THE INVENTION

This invention relates to light emitting devices, such as displays and lamps, and more particularly relates to such devices incorporating phosphors.

Perhaps the most widely known display device which employs a phosphor display screen is the color cathode ray tube employed in televisions and computer monitors. The phosphors used are cathodoluminescent, that is, excitable by cathode rays from the electron gun in the neck of the tube. Conversion of the cathode rays to visible light is relatively energy intensive, with operating voltages of 20 to 30 kV being typical. Moreover, the conversion must take place in a vacuum, which is maintained by the sealed glass envelope of the tube.

Attempts have been made to flatten the conventional cathode ray tube, in order to broaden the range of applications. However, the most successful implementation of flat display devices so far has been the liquid crystal display (LCD). Due in part to its lower energy consumption and lack of the need for a vacuum environment, the LCD is widely used in portable computers, and other special purpose display applications, such as watches, calculators and instrument panels.

However, there are draw-backs to LCDs as well. For example, the display characteristics of LCD computer screens, such as color, brightness and contrast, are sometimes dependent on the angle of view, while phosphor screens have no such angle-dependence of their display characteristics.

Lamps incorporating phosphors are also known. For example, conventional fluorescent lamps have a coating of a UV-excitable phosphor on the inside surface of the lamp's glass envelope. In operation, Hg in the lamp fill emits UV radiation, which excites visible light emissions from the phosphor coating. However, like CRTs, such lamps require a glass envelope to maintain a suitable environment (Hg vapor) for UV emission.

Light emitting devices are known in which the visible (blue) light from an LED is enhanced by a fluorescent screen coupled to the LED (Japanese Patent Abstract of Application 07176794) or by a fluorescent dye impregnated into a resin encapsulating the LED (Japanese Patent Abstract of Application 5-152609).

A display device described in Japanese Patent Abstract of Application 62-189770, includes an infra-red emitting LED and a fluorescent layer for converting the infra-red radiation to visible light. Such long-to-short wavelength energy conversions are not very efficient.

OBJECTS AND SUMMARY OF THE INVENTION

Accordingly, it is an object of the invention to provide light emitting devices based on luminescent phosphors, which devices are relatively energy efficient.

It is another object of the invention to provide such light emitting devices which do not require a vacuum environment for their operation.

It is another object of the invention to provide such light emitting devices which have a flat or slim profile.

It is another object of the invention to provide a color display device which satisfies one or more of the above objects.

It is yet another object of the invention to provide a lamp which satisfies one or more of the above objects.

In accordance with one aspect of the invention, a visible light emitting device comprises a phosphor screen of one or more UV-excitable, visible light-emitting phosphors, and a source of UV radiation for exciting visible light emission from the phosphor screen, characterized in that the UV source consists of at least one GaN-based light emitting diode (LED) or laser.

In accordance with one embodiment of the invention, the LED is a multilayer epitaxial structure on a single crystal substrate, the structure comprising a first GaN contact layer of a first conductivity type on the substrate, a first $In_xAl_yGa_{1-x-y}N$ cladding layer of the first conductivity type on the contact layer, an active region of $Al_yGa_{1-y}N$ on the first cladding layer, an $In_xAlyGa_{1-x-y}N$ cladding layer of a second conductivity type on the active region, a second GaN contact layer of the second conductivity type on the second cladding layer, and a top metal contact layer on top of the second GaN contact layer.

In accordance with a preferred embodiment, the first conductivity type is n and the second conductivity type is p, and the first contact layer is n+ GaN, the first cladding layer is n $In_xAl_yGa_{1-x-y}N$, the second cladding layer is p $In_xAlyGa_{1-x-y}N$, and the second contact layer is p+ GaN.

The active region may be a single quantum well structure or a multi quantum well structure. The substrate may be of a material which is transmissive to visible light, such

as sapphire, silicon carbide or zinc oxide, and the phosphor screen is located on or adjacent to the substrate. Alternatively, the top metal contact layer is transmissive to visible light, and the phosphor screen is located on or adjacent to the top metal contact layer.

In accordance with a preferred embodiment, the LED includes a resonant cavity (RC), and is defined by at least one distributed Bragg reflection (DBR) region located between one of the cladding layers and its contact layer. A second DBR region may be located between the other cladding layer and its contact layer. In the alternative, a reflective metal layer is used, such as the top metal contact layer. The distance between the two reflective surfaces defines the cavity width. Typically, this width is approximately $\lambda/2n$, and the active region is located in the antinode of the cavity.

In accordance with another aspect of the invention, the light emitting device is a display device in which the phosphor screen comprises an array of phosphor elements, and the array is photo pumped by a row of LEDs which scans the array with UV light in accordance with a display signal. The scanning may be achieved either by moving the row of LEDs or by using optical scanning means, such as a rotating prism.

In accordance with another embodiment, a display device is comprised of a matrix array of individually addressable LED-phosphor devices.

In accordance with another aspect of the invention, a lamp is comprised of a matrix array LED-phosphor devices which are addressed en banc.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a cross section of one embodiment of an LED-phosphor structure of the invention, in which the phosphor is located on top of the LED;

Fig. 2 is a cross section of another embodiment of an LED-phosphor structure of the invention, in which the phosphor is located on the substrate under the LED;

Fig. 3 is a cross section of yet another embodiment similar to that of Fig. 1, except that the LED includes a resonant cavity;

Fig. 4 is a cross section of yet another embodiment similar to that of Fig. 2, except that the LED includes a resonant cavity structure;

Fig. 5 is a schematic illustration of one embodiment of a color display device in which a row of LEDs is scanned across a screen of color phosphor elements;

Fig. 6 is a schematic illustration of another embodiment of a color display device similar to that of Fig. 5, except that the row of LEDs is stationary, and the screen is optically scanned;

Fig. 7 is a schematic illustration of yet another embodiment of a color display device of a matrix of individually addressable LED-phosphor picture elements;

Figs. 8(a) through 8(g) are cross-sections illustrating stages in the fabrication of a row of picture elements of the device of Fig. 7;

Fig. 9 is a schematic circuit diagram of a portion of the matrix display of Fig. 7;

Fig. 10 is a cross section of a portion of the LED structure of Fig. 4, showing the structures of the bottom and top DBR layers;

Fig. 11 is a schematic diagram of yet another embodiment of a color projection system of the invention, using a single UV LED and x and y scanning optics to scan a phosphor screen; and

Fig. 12 is a schematic diagram of a variation of the color display device of Fig. 5, employing three rows of LEDs.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following is a detailed description of how to use GaN- based (InAlGaN) light emitting diodes (LEDs) as a source of UV radiation for use in photo pumping phosphors for display and lighting applications in the visible range.

This UV LED-phosphor device requires a simple GaN-based LED, which typically has a broad spectrum with a peak around 363 nm and emission which tails into the visible range. This tail is not very useful for photo pumping visible range phosphors. Therefor, microcavities, sometimes referred to herein as resonant cavities, are introduced into the LEDs to narrow the width of the emission band and raise the peak emission.

Fig. 1 shows in cross section a simple structure for a UV LED/phosphor device 10. On a single crystal substrate 12, of for example, sapphire, silicon carbide or zinc oxide, is located an epitaxial buffer/contact layer 14 of n+ GaN. On this buffer layer is the LED structure including the following epitaxial layers in sequence: lower cladding layer 16 of n AlGaN, active region 18 of i GaN, and upper cladding layer 20 of p AlGaN. On top of this LED structure is a p+ GaN contact layer 22, semi-transparent metal contact layer 24, of for example a Au/Ni alloy, and voltage electrode 26, with phosphor layer 28, of a UV-excitable phosphor, on contact layer 24. Metallization layers 30 and 34, of for example, Al, are provided on the surface of buffer/contact layer 14 on either side of the LED structure. Layer 30 provides grounding via grounding electrode 32, while layer 34 serves as an addressing electrode.

To enhance its transparency to UV, the contact layer 22 or the metallization layer 24 preferably has an anti-reflective coating on its upper surface. Such a coating should have low reflectivity and low absorption in the UV (eg., below 450 nm), and high reflectivity and low absorption in the visible wavelength range (eg., 450-650), to prevent light generated in the phosphor layer from backscattering into the device structure. Such coatings, for example, a 1/4 wave stack (Bragg reflector), are well-known, and not a necessary part of this description.

In operation, UV radiation is emitted from the active layer 18, substantially in one direction, as indicated by the large arrow, then passes through semi-transparent contact layer 24 to land on phosphor layer 28, and excite visible radiation from the phosphor. The phosphor emission has a lambertian distribution, as indicated by the smaller arrows.

Fig. 2 shows a second embodiment 40 of a simple UV LED/phosphor device, in which the phosphor layer is located on the underside of a UV transparent single crystal substrate, of, for example, single crystal sapphire, silicon carbide or zinc oxide. To enhance its transparency to UV, the substrate is preferably relatively thin, eg., on the order of 100 microns, polished and having an anti-reflective coating on its lower surface, of the type formed on the upper surface of the device of Fig. 1.

Located on the substrate 42 is an epitaxial buffer/contact layer 44 of n+ GaN. On this buffer layer is the LED structure including the following epitaxial layers in sequence: lower cladding layer 46 of n AlGaN, active region 48 of GaN, and upper cladding layer 50 of p AlGaN. On top of this LED structure is a p+ GaN contact layer 52, metal contact layer 54, and a voltage electrode 56. The UV excitable phosphor layer 64 is located on the underside of the transparent substrate 42. Preferably, the substrate is kept relatively thin, consistent with the needed mechanical strength, for example, around 100 micrometers, to maximize its transparency to UV radiation. Buffer/contact layer 44 is grounded by grounding electrode 60 via metallization layer 58, while layer 62 serves as an addressing electrode.

In either of the above structures, the active region could be a single or multi-quantum well structure, the multi-quantum well structure being better suited for higher power applications, as is known.

A resonant cavity (RC)LED/phosphor device is shown in Fig. 3. The device 70 includes on a single crystal substrate 72, an n+ GaN contact layer 74, a back Distributed Bragg Reflection (DBR) layer 76. By way of example, for a resonance wavelength of 380 nm, such a DBR would have 15 or more layers of alternating high and low refractive index, the high index layers being of GaN (r.i. = 2.65) and the low index layers being of Al_xGa_1.

${}_xN$, where x = 0.25 (r.i. = 2.4); and the thickness of the high index layers being about 3585A and that of the low index layers being about 396A.

On this back DBR layer is formed a bottom cladding layer 78 of n AlGaN, active layer 80 of GaN, InGaN or AlGaN, a top cladding layer 82 of p AlGaN, a second output DBR layer 84, similar in structure to the first back DBR layer 76, but having a greater UV transmission, according to the relation

$$1 - R_{out} > 1 - R_{back}$$

achieved by having a smaller number of layers than the back DBR. Typically, the reflectivity of the back DBR would be 90 percent or more, while that of the output DBR would be in the range of 60 to 70 percent. In addition, the DBR layers must satisfy the condition

$$2\alpha d << 1 - R_{out}$$

where d is the distance between the inner reflective surfaces of the DBR layers 76 and 84, which defines the width of the resonant cavity, n is the refractive index and α is the absorption coefficient of the cavity, respectively, whereby quenching of the resonance is avoided.

On top of the output DBR layer 84 is formed top contact layer 86 of p+ GaN, UV semi-transparent metallic contact layer 88, and phosphor layer 90. Electrodes 92, 94 and 96 complete the structure.

The distance d is determined by the equation;

$$\phi_{out}(\lambda) + \phi_{back}(\lambda) + 4\pi nd/\lambda = 2N\pi ,$$

where N is an integer (usually 1), $\phi_{out}(\lambda)$, $\phi_{back}(\lambda)$ are phase changes during reflection at the output and back-mirror, respectively, λ is the resonant wavelength, and d and n are the cavity width and refractive index, respectively.

If the mirrors are formed by DBR, then phase change is either so small as to be negligible if the first layer of the DBR (the layer in contact with the cladding layer) is a high index layer, or $\pi/2$ if the first layer is a low index layer.

In the case of a metallic mirror, phase change is determined by the equation:

$$\phi_m = \arctan(2 n k_m /(n^2 - n_m^2 - k_m^2) ,$$

where n_m, k_m real and imaginary part of the refractive index of the mirror and n is the refractive index of the cavity.

The presence of such a resonant cavity in the LED structures of the invention has a tendency to result in more directional (non-lambertian) emissions, and strongly enhances emissions normal to the layer surfaces at the resonant wavelength, with a shift to the shorter wavelengths with increasing angle of emission away from the normal direction.

Another advantage of the directionality of the radiated beam of the RCLED is that it enables the use of focusing optics with a reduced aperture.

As an alternative to the arrangement shown in Fig. 3 in which the phosphor layer is deposited on the top contact layer, the phosphor layer could be deposited on the bottom of a UV transparent substrate, and the positions of the back and output DBR layers would be reversed.

Another alternative resonant cavity structure 100 is shown in Fig. 4. This structure, built onto UV transparent substrate 102, begins with n+ contact layer 104 of AlGaN, on top of which is output DBR 106, supporting bottom cladding layer 108 of n- InAlGaN; next are the active layer 110 and top cladding layer 112, of p InAlGaN. On layer 112 is formed top DBR layer 114, and top contact layer 116 of p+ AlGaN. Completing the structure is top metallic contact 118, and electrodes 124 and 126.

The individual sub-layers of the top and bottom DBR layers 106 and 114 of the device of Fig. 4 are shown in Fig. 10. Such DBR layers are composed of sub-layers of alternating high and low refractive index. The reflectivity of the DBR layers is determined by the number of sub-layers and the difference in refractive index between the high and low index sub-layers. Suitable high index materials for the top back reflective DBR layer include Si_3N_4, MgO, TiO_2, MgF_2, HfO_2, Ta_2O_5 and ZnS; while suitable low index materials include SiO_2, Al_2O_3, CaF_2 and HfF_4. Layer 114 is composed of 12 sub-layer of SiO_2 (r.i. = 1.56) alternating with 11 sub-layers of Si_3N_4 (r.i. = 2.09), each sub-layer having a thickness of 1/4 λ. The output DBR layer 106 is composed of five sub-layers of $Al_xGa_{1-x}N$ (r.i. = 2.7) alternating with four sub-layers of $Al_yGa_{1-y}N$ (r.i. = 2.3), each sublayer having an optical thickness nd of 1/4 λ. For a λ of 380 nm, the thicknesses of the high and low index layers of the back DBR are 455 and 609A, respectively, while the thicknesses of the high and low index layers of the output DBR are 352 and 413 A, respectively.

In an alternative arrangement, the back DBR 114 may be eliminated and instead the reflective lower surface of the top metal contact layer 116 is relied upon to define the back surface of the resonant cavity. The reflectivity of such a metallic mirror is independent of the angle of incidence of the reflected radiation, and provides good electrical contact to adjacent layers. Aluminum is a particulary good UV reflective material.

Another advantage of this arrangement is that the structure can be tuned to the maximum output by regrowth of the p+ contact layer 118 to change the length d of the resonant cavity.

Instead of having the phosphor layer deposited directly on the LED structure, the phosphor layer can be deposited on a separate substrate, and the LED can be positioned in close proximity, where it will photo-pump the phosphor layer. This decoupling of the LED and the phosphor layer makes possible a multicolor display device, wherein an array of different color phosphor pixels on a substrate such as a display window can be scanned by a moving LED or array of LEDs, with the intensity of the LED outputs controlled by a display signal, eg., a video signal. A principal advantage of such an arrangement is that a multicolor display may be obtained without the necessity of fabricating different LED structures for each of the desired colors of emission. Thus, the LED array can be an array of identical devices, which can be formed simultaneously on a single substrate.

One such arrangement 200 for a color display is shown schematically in Fig. 5, in which phosphor display screen 210 is composed of a repetitive pattern of R, G, B triplets 212, 214, 216 of vertically oriented stripes of phosphors which emit red, green and blue light, respectively, upon excitation by UV radiation. The UV exciting radiation is supplied from a horizontal row 218 of UV emitting LEDs or lasers, identified as R, G, B, to indicate the particular phosphor stripes which they excite, ie, LED 220 excites stripe 212, LED 222 excites stripe 214, LED 224 excites stripe 216, and so on. As can be seen from Fig. 5, the LED row only excites a portion of each stripe, shown as the horizontal row 226 on the display screen 210. This row defines a single row of pixels of the display. In order to excite additional rows, the LED row is scanned vertically along the screen, as indicated by the arrows, in synchronism with the display signal. A display input signal 230 controls the intensity of the UV output of the individual LEDs as it scans the display screen, thereby to create a full color display.

Instead of a single row of LEDs, multiple rows (eg., three) could be used to scan the screen. In such an arrangement, shown for three rows 218a, 218b and 218c of LEDs in Fig. 12, during each addressing period for a row 226 of phosphor elements, each row of LEDs is addressed with the same signal information, but with a time delay. Thus, row 218c is addressed first, then row 218b, and finally row 218a. For example, pixel R is illuminated by the three LEDs in column C1, G by the LEDs in C2, etc., so that each pixel is illuminated three times in succession with the same display information during each row addressing period, thereby increasing the brightness of the display three times without sacrificing

resolution of the display image.

Another embodiment of a color display device 300 of the invention is shown in Fig. 6. This device is similar to that shown in Fig. 5, in having a phosphor screen 310 composed of triplets (312,314,316) of vertical phosphor stripes, and a row 318 of LEDs (320,322,324) for exciting the screen with UV radiation in accordance with a display input signal 330. However, instead of the row scanning vertically along the screen as in the device of Fig. 5, the row remains stationary, and the exciting UV radiation is scanned optically by means of rotating prism 326, which rotates about an axis A in the direction indicated by the arrows, in synchronism with the display signal.

Another embodiment of a scanning system for a projection display is shown in Fig. 11. In this embodiment, a single UV emitting LED or laser 610 is used. UV light from LED 610 is focussed by lens 612 into a beam and directed to prism 614, which spins about its axis A to achieve scanning of the beam in the x direction across phosphor screen 618. However, prior to landing on screen 618, the beam is reflected from mirror 616, which spins about its axis A' to achieve scanning of the beam in the y direction on the screen 618.

Another way of achieving a color display device using the invention is to directly deposit layers of different color phosphors onto the output side, for example, the top, semi-transparent electrode surfaces of an array of UV emitting LEDs.

Such a color display device 400 of the invention is shown in Fig. 7. In this embodiment, a two dimensional matrix 402 of individually addressable R,G,B picture elements (402,404,406, etc) are driven in the conventional line-at-a-time manner, using row and column drivers 410 and 412, respectively, which receive display information from input signal source 414.

The picture elements each consist of a UV emitting LED having an active region of InGaN, and the LEDs are covered with a layer of a UV excitable, visible light emitting phosphor.

Various stages of one of many possible techniques for producing the phosphor pattern on such a matrix display are represented by the cross sections of one row of picture elements in Figs. 8(a) through (f). This is a particularly advantageous process in that it is self registering, as will become apparent from the following description.

In Fig. 8(a), substrate 500 supports a row of LEDs 502, 504, 506, etc, having identical structures similar to that of the LED of Fig. 1 or the RC LED of Fig. 3. Deposited on the LEDs is a layer of a red phosphor/photoresist slurry composition 508, the photoresist component of which becomes insoluble upon being exposed to UV radiation. The layer 508

is selectively exposed to UV light by activation of the LEDs corresponding to the red picture elements of the display, rendering the layer surrounding these LEDs insoluble. The layer is then developed, ie, the unexposed portions of the layer are removed by treatment with a solvent, leaving red layers 510 on the "red" LEDs. This procedure is then repeated for the green picture elements, by coating the array with a green slurry composition 512, selectively activating the LEDs corresponding to the green picture elements to selectively insolubilize the photoresist, developing to remove the still soluble portions and leave green layers 514 on the "green" LEDs. Finally, the procedure is repeated for the "blue" LEDs, using blue slurry coating 516 to leave blue layers 518 on the "blue" LEDs.

Depending upon their design, the emission spectrum of the LEDs may extend from the UV into the blue region of the visible spectrum. In this case, since the LEDs have some blue emission in addition to the UV emission, the blue LEDs may be left uncoated, as shown in Fig. 8(g).

As an alternative to the above slurry coating technique, the LEDs may be coated by the so-called dusting technique, in which a UV sensitive photoresist is coated onto the LED array, and then selected portions of the coating are exposed to insolubilize them. This exposure step also results in the photoresist surface becoming tacky. While in this tacky stage, the coating is dusted with a dry powder of phosphor particles, which particles adhere to the tacky surface. The coating is then developed by rinsing away the non-exposed portions.

Use of a UV sensitive photoresist in the above process enables selective exposure by the selective activation of the LED elements. This of course requires the fabrication of the addressing circuitry and its inter-connection to the row and column drivers prior to phosphor coating. A schematic diagram of an exemplary driving scheme is shown in Fig. 9, in which four columns X1, X2, X3, X4, and four rows Y1, Y2, Y3, Y4 of a matrix array are shown, with an array of LEDs interconnected to the rows and columns. By the selective application of signals IF to the rows and columns, any one LED or an entire row or column of LEDs, or other combination of LEDs may be activated simultaneously.

Typical UV excitable phosphors which may be used in the devices of the invention are:

red YO_2S_2:Eu
green ZnS:Cu, Ag
blue $BaMgAl_{10}0_{17}$:Eu

The image of such a color matrix display could either be viewed directly or could be

projected onto a wall or screen by the use of projection optics.

In the above described color matrix display, the various picture elements are individually and selectively addressed in order to produce a color display such as a video image. However, it will be appreciated that if all of the elements are activated simultaneously, the device becomes a lamp, emitting a white light having a color temperature determined by the color coordinates and intensities of the individual R,G,B elements. Moreover, the color temperature can be adjusted by changing the intensity, as well as the composition and mix of the individual color elements. Such lamps are of course intended to be included within the scope of the invention.

In the alternative, such lamps could emit different colors of light in rapid sequence, by the sequential activation of selected ones of the LEDs. For example, activating all red, then all green, then all blue LEDs would provide a source of alternating red, blue and green light, which would be useful as a back light in combination with a light valve such as a liquid crystal display, to form a frame sequential color display system. As is known, such systems rely upon the sequential display of the separate red, blue and green components of a color display signal at a frequency such that the observer integrates the separate components into a full color display image.

The invention has been described in terms of a limited number of embodiments. Other embodiments and variations of embodiments will become apparent to those skilled in the art, and are intended to be encompassed within the scope of the invention, as defined by the accompanying claims.

CLAIMS

1. A visible light emitting device comprising a phosphor screen of one or more UV-excitable, visible light-emitting phosphors, and a source of UV radiation for exciting visible light emission from the phosphor screen, characterized in that the UV source consists of at least one GaN-based light emitting diode (LED).

2. The light emitting device of claim 1 in which the LED is a multilayer epitaxial structure on a single crystal substrate, the structure comprising a first GaN contact layer of a first conductivity type on the substrate, a first $In_xAl_yGa_{1-x-y}N$ cladding layer of the first conductivity type on the contact layer, an active region of $Al_yGa_{1-y}N$ on the first cladding layer, an $In_xAlyGa_{1-x-y}N$ cladding layer of a second conductivity type on the active region, a second GaN contact layer of the second conductivity type on the second cladding layer, and a top metal contact layer on top of the second GaN contact layer.

3. The light emitting device of claim 2 in which the first conductivity type is n and the second conductivity type is p.

4. The light emitting device of claim 3 in which the first contact layer is n+ GaN, the first cladding layer is n $In_xAl_yGa_{1-x-y}N$, the second cladding layer is p $In_xAlyGa_{1-x-y}N$, and the second contact layer is p+ GaN.

5. The light emitting device of claim 2 in which the active region comprises a single quantum well structure.

6. The light emitting device of claim 2 in which the active region comprises a multi quantum well structure.

7. The light emitting device of claim 2 in which the substrate is transmissive to visible light.

8. The light emitting device of claim 7 in which the substrate is selected from the group consisting of sapphire, silicon carbide and zinc oxide.

9. The light emitting device of claim 7 in which the phosphor screen is located on or adjacent to the substrate.

10. The light emitting device of claim 2 in which a light transmissive top metal contact layer is transmissive to visible light.

11. The light emitting device of claim 10 in which the phosphor screen is located on or

adjacent to the light transmissive top metal contact layer.

12. The light emitting device of claim 2 in which the LED includes a resonant cavity (RC).

13. The light emitting device of claim 12 in which the RC is defined by at least one distributed Bragg reflection (DBR) region located between one of the cladding layers and its contact layer.

14. The light emitting device of claim 13 in which a second DBR region is located between the other cladding layer and its contact layer.

15. The light emitting device of claim 13 in which the DBR region is located between the n cladding layer and its n+ contact layer, and the bottom surface of the top metal contact layer is UV reflective.

16. The light emitting device of claim 1 in which the phosphor screen comprises an array of phosphor elements.

17. The light emitting device of claim 16 in which the array comprises a repetitive pattern of triplets of mutually parallel stripes of red, green and blue emitting phosphors.

18. The light emitting device of claim 17 in which the UV source comprises a row of LEDs oriented adjacent to the screen and transverse to the phosphor stripes..

19. The light emitting device of claim 18 in which means are included for repetitively scanning the stripes with the UV output from the LEDs.

20. The light emitting device of claim 19 in which such means comprises means for repetitively moving the row of LEDs along the stripes behind the screen.

21. The light emitting device of claim 19 in which such means comprises optical scanning means located between the row of LEDs and the screen.

22. A display device comprising a two dimensional array of individually addressable picture elements, each element comprising a UV emitting LED, and at least some of the elements also comprising a layer of UV excitable, visible light emitting phosphor.

23. The display device of claim 22 in which the picture elements are arranged in a repetitive pattern of R,G,B triplets.

24. The display device of claim 23 in which the LEDs corresponding to the R picture elements are covered with a layer of red phosphor, and the LEDs corresponding to the G picture elements are covered with a layer of green phosphor.

25. The display device of claim 24 in which the LEDs corresponding to the B picture elements are covered with a layer of blue phosphor.

26. A lamp comprised of a matrix array of individual LED-phosphor devices which are

addressed en banc.

27. A method of producing a light emitting device comprising an array of individually addressable UV emitting LEDs and an array of phosphor elements, each phosphor element associated with an LED, and each phosphor element emitting visible light in one of at least first and second colors upon excitation by the LED with which it is associated, the method comprising the steps of:

(a) depositing on the LED array a layer of a phosphor/photoresist slurry composition;

(b) addressing a first set of LEDs associated with the first phosphor color, in order to selectively expose the layer to UV radiation and thereby selectively insolubilize the layer;

(c) contacting the layer with a solvent to remove the still soluble portions of the layer; and

(d) repeating steps (a), (b) and (c) for the second phosphor color;

whereby a pattern of phosphor elements of the first and second colors are left on the LEDs in accordance with the pattern of exposure of the layers by the LEDs.

28. A method of producing a light emitting device comprising an array of individually addressable UV emitting LEDs and an array of phosphor elements, each phosphor element associated with an LED, and each phosphor element emitting visible light in one of at least first and second colors upon excitation by the LED with which it is associated, the method comprising the steps of:

(a) depositing on the LED array a layer of a photoresist composition;

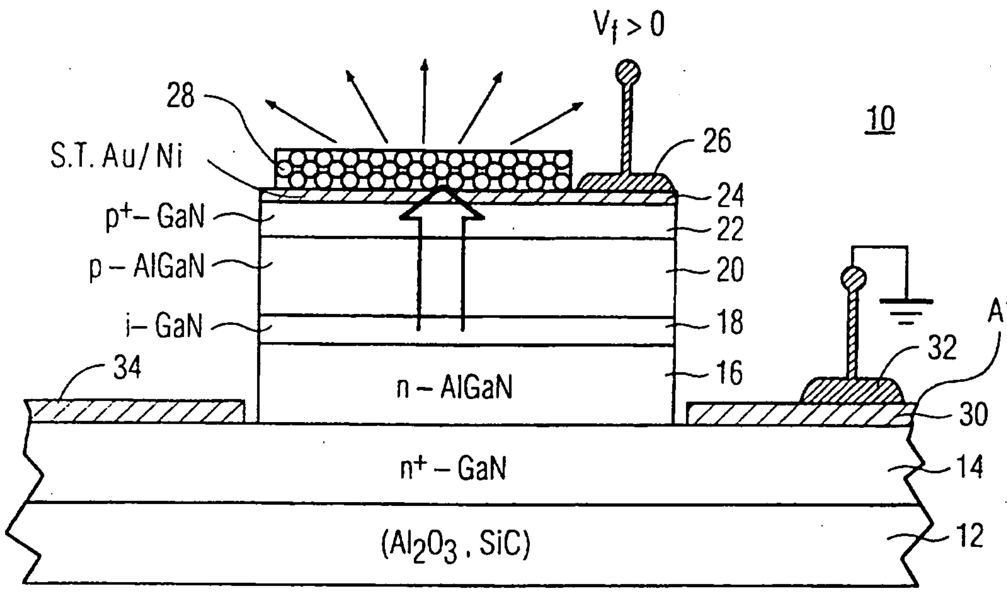
(b) addressing a first set of LEDs associated with the first phosphor color, in order to selectively expose the layer to UV radiation to thereby selectively insolubilizing the layer;

(c) adhering phosphor particles of the first color to the layer;

(d) contacting the layer with a solvent to remove the still soluble portions of the layer; and

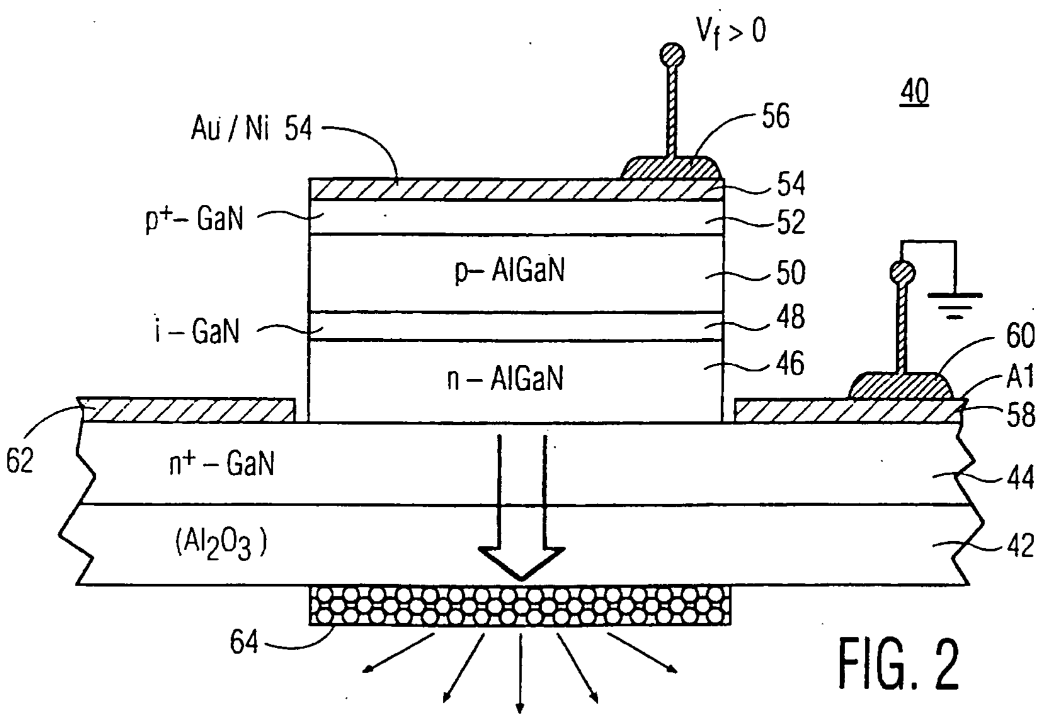
(e) repeating steps (a), (b) (c) and (d) for the second phosphor color;

whereby a pattern of phosphor elements of the first and second colors are left on the LEDs in accordance with the pattern of exposure of the layers by the LEDs.



$V_f > 0$
28
S.T. Au/Ni
p^+– GaN
p – AlGaN
i– GaN
34
n – AlGaN
n^+ – GaN
(Al_2O_3, SiC)
26
24
22
20
18
16
10
A1
32
30
14
12

FIG. 1



$V_f > 0$
Au / Ni 54
p^+– GaN
p– AlGaN
i – GaN
n – AlGaN
n^+ – GaN
(Al_2O_3)
62
64
56
54
52
50
48
46
40
60
A1
58
44
42

FIG. 2

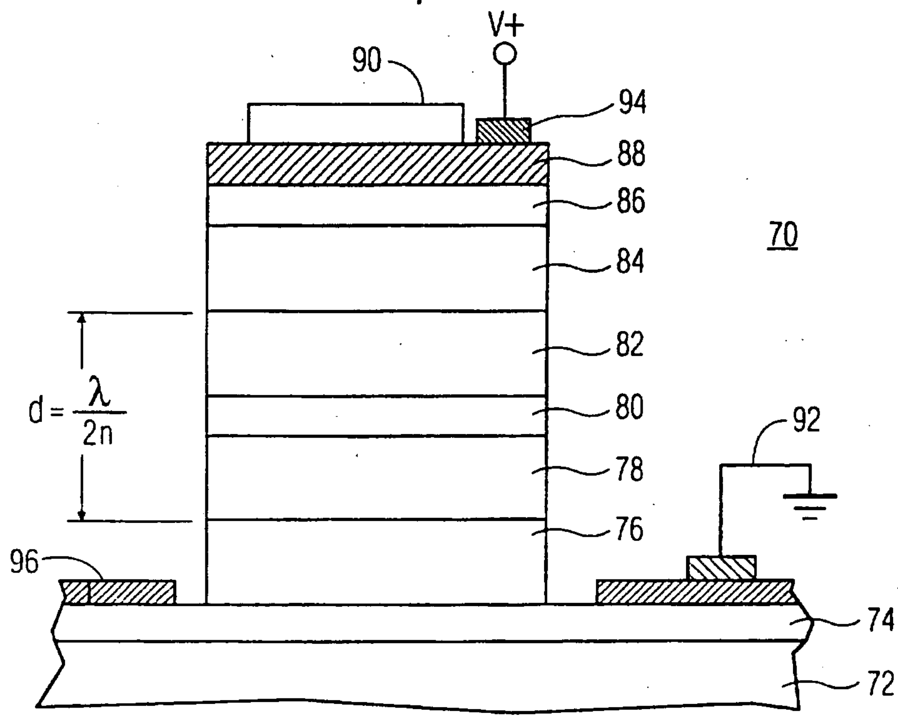

V+
90
94
88
86
84
82
80
78
76
70
$d = \frac{\lambda}{2n}$
92
96
74
72

FIG. 3

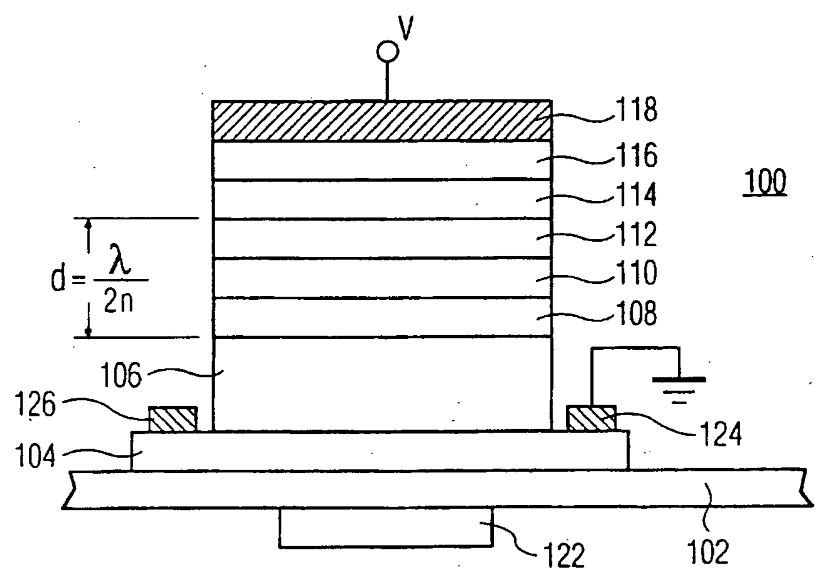

V
118
116
114
112
110
108
100
$d = \frac{\lambda}{2n}$
106
126
124
104
122
102

FIG. 4

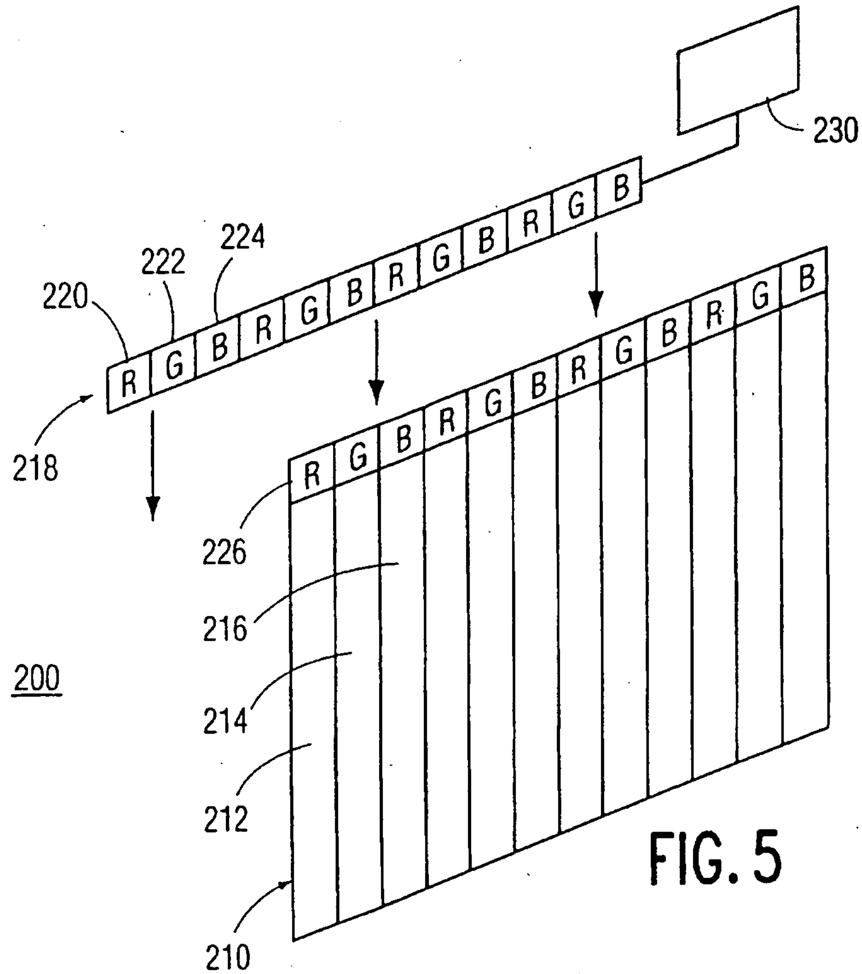

230
B
R
G
B
R
G
B
R
G
B
R
G
B
224
222
220
R
G
B
R
G
B
R
G
B
R
G
B
218
226
216
200
214
212
210

FIG. 5

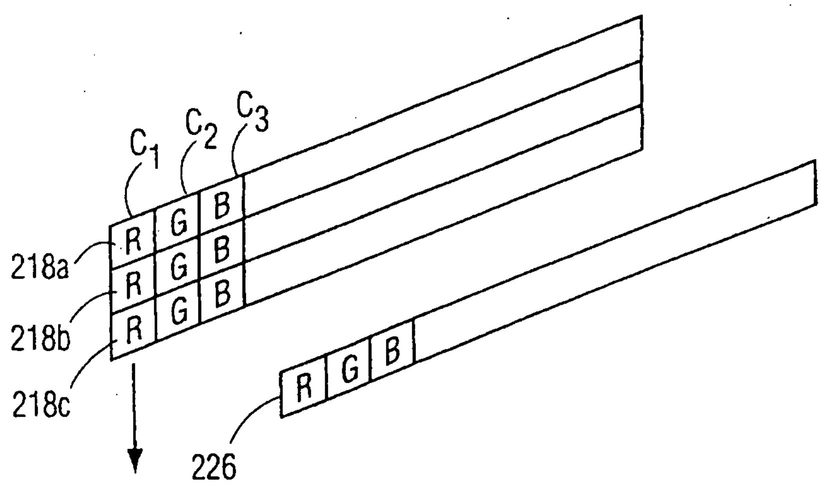

C_1
C_2
C_3
R G B
R G B
R G B
218a
218b
218c
R G B
226

FIG. 12

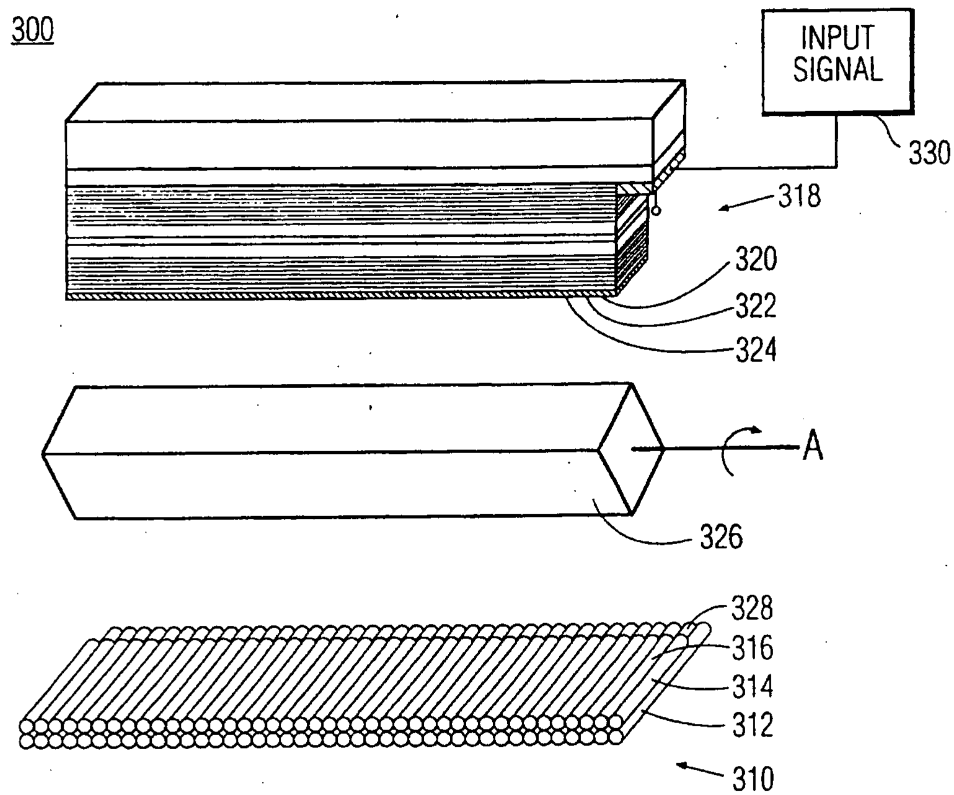


FIG. 6

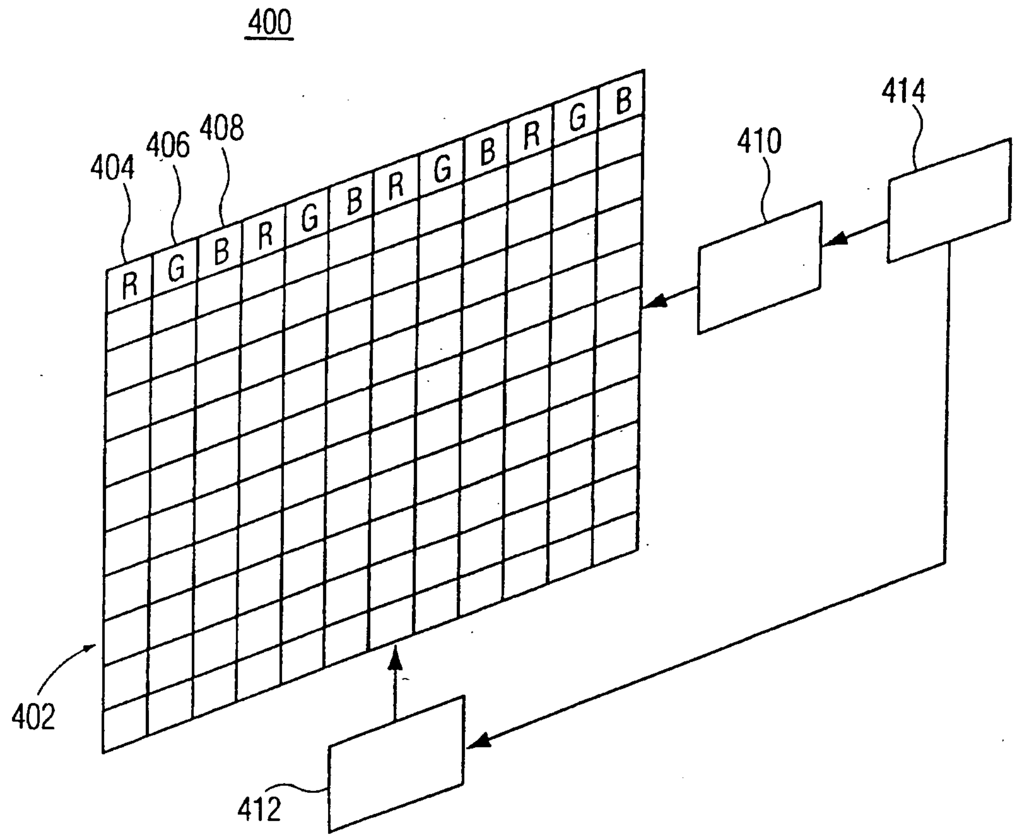


FIG. 7

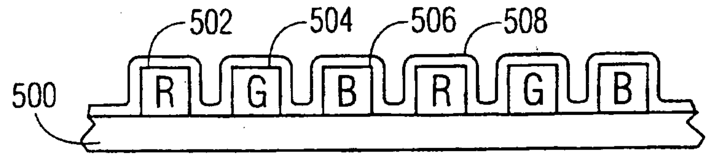


FIG. 8A

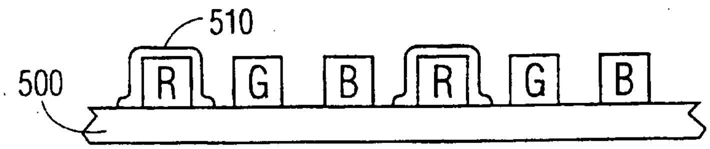


FIG. 8B

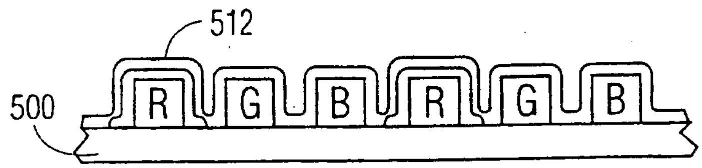


FIG. 8C

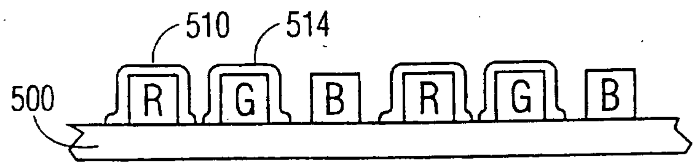


FIG. 8D

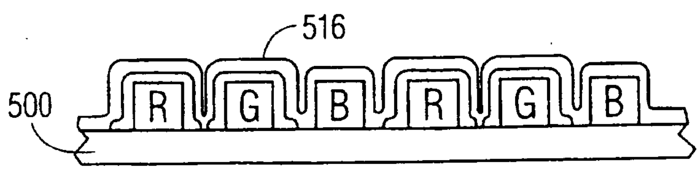


FIG. 8E

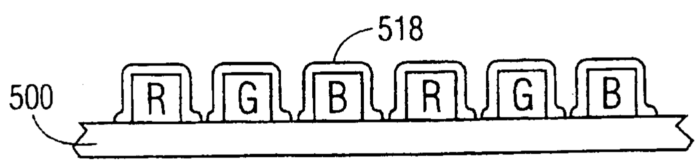


FIG. 8F

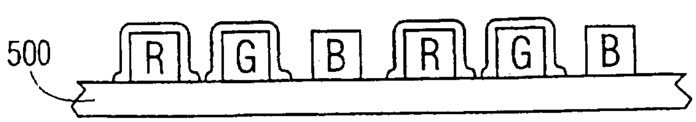


FIG. 8G

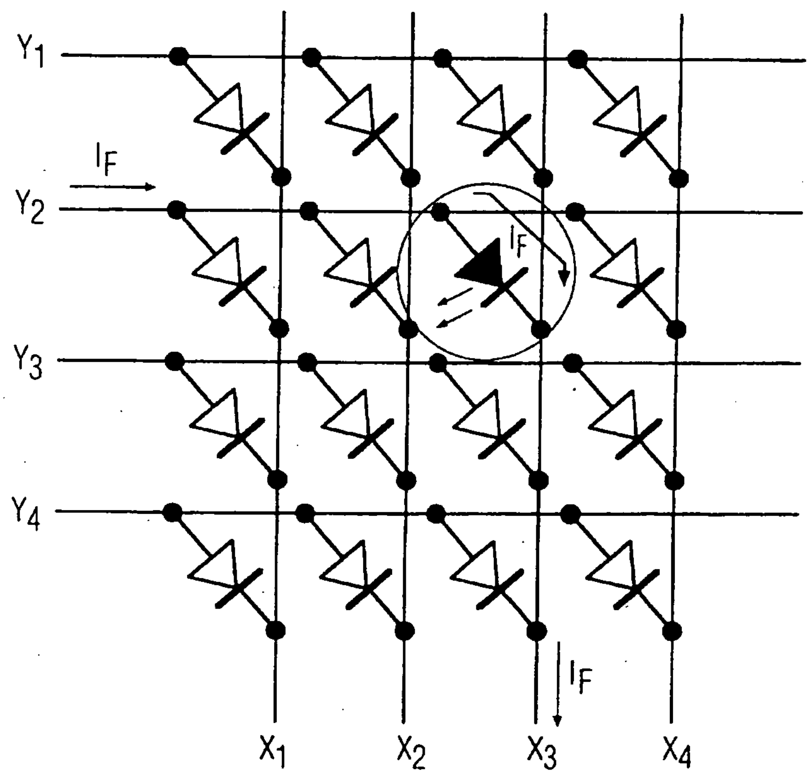


FIG. 9

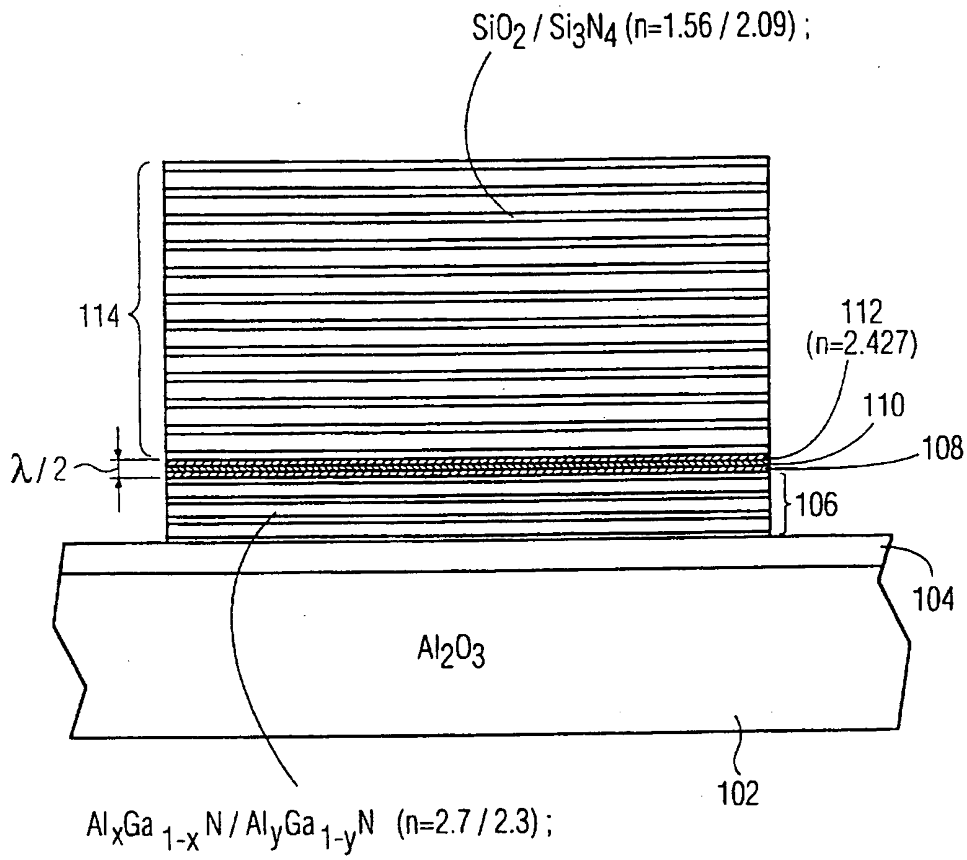

SiO_2 / Si_3N_4 (n=1.56 / 2.09) ;
114
112
(n=2.427)
110
108
λ/2
106
104
Al_2O_3
102
$Al_xGa_{1-x}N / Al_yGa_{1-y}N$ (n=2.7 / 2.3) ;

FIG. 10

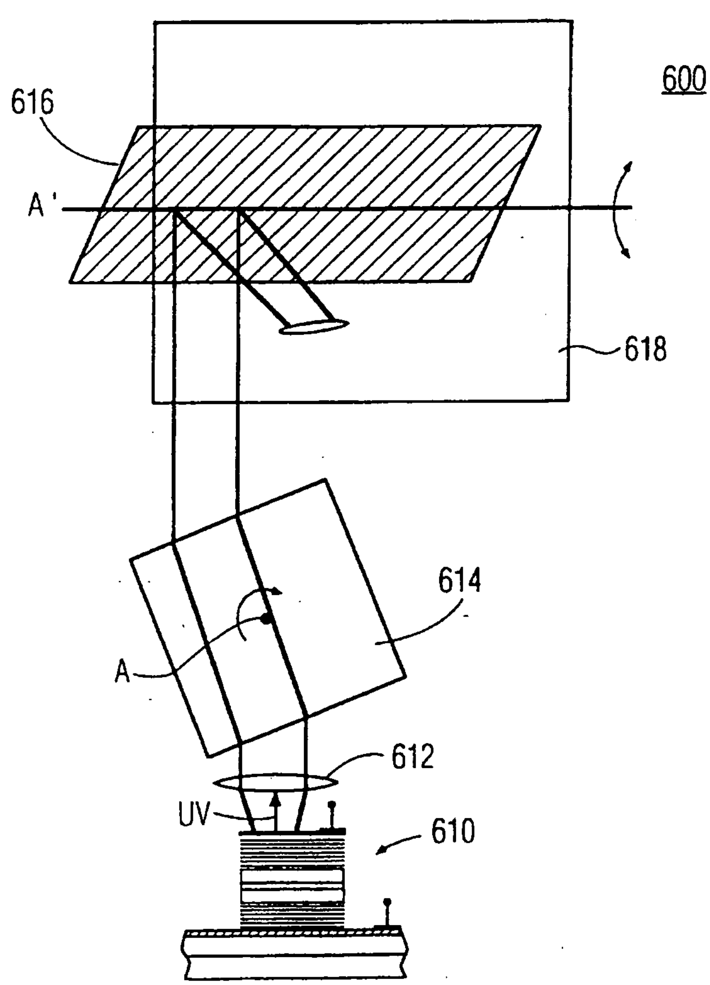


FIG. 11